eLoran Performance in the Orkney Archipelago

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ABSTRACT. In order to understand the limiting factors of eLoran coverage and performance, and to gain confidence that eLoran can serve as a backup and complement to GNSS in maritime applications (particularly harbour entrance and approach), we must assess the performance of the system in "difficult" environments. One such environment is that of densely packed island regions – or archipelagos.

This paper presents the results of a recent GLA sea-trial intended to assess the performance of eLoran in and around a typical archipelago. The trial took place over four days in the Orkney Islands, off the northeast coast of mainland Scotland. This group of islands is within a region of excellent station geometry, and very good Loran signal strength is available from at least four stations. Performance can vary depending on the proximity of land to the vessel's passage due to the coastal recovery effect, the density of any spatial ASFs provided in those regions, or the time constant of GPS calibration.

The paper presents the rationale for the trial, the equipment and software used, the analysis methods employed, and the results. The paper also summarises the GLAs' further plans in regard to eLoran trials.

1. INTRODUCTION AND BACKGROUND. There is wide support for eLoran in Europe, the UK continues to operate their Loran station at Anthorn in Cumbria. The French are committed to Loran and will run their two stations until 2020. Norway continues to run their stations; and the European eLoran forum has brought together these and other interested administrations to try to ensure a future for eLoran in Europe. However, the Finnish Maritime Administration has raised concerns about the performance of eLoran in regions of densely packed islands – so called archipelagos.

Figure 1 shows the area they are interested in; the southwest coast of Finland. Figure 2 shows a view of the coastline highlighted in yellow to emphasize the structure of the archipelago.

Figure 1 – The red rectangle shows the location of Skandinavian archipelagos.

Now although the islands are densely packed, the terrain is actually quite flat. There are no mountains, causing shadowing, extra path lengths, and refraction. But there are highly varying coastline profiles as vessels steam past islands and channels either widen or become narrow. Also, it is a well-known fact that Additional Secondary Factors (ASFs) show a recovery effect as signals propagate over a boundary between land and sea. So we would expect to see rapid changes in propagation effects along a vessel's track. These could indeed be cause for concern.

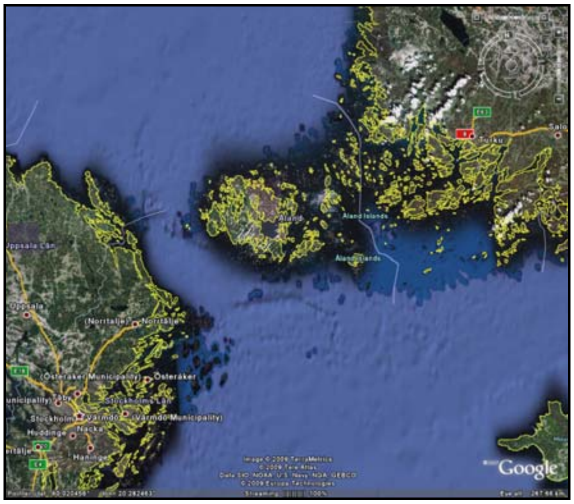

Figure 2 – A close-up view of the Skandinavian islands.

Figure 3 – The location of the Orkney Islands, the green dot above Scotland.

2. TRIAL AIM. So the aim of the Orkney Island trial was to try to investigate this concern using a region very similar in nature to the Scandinavian islands but based in the UK.

Figure 3 show the location of the Orkney Islands, lying some 20km or so from northeast Scotland in an area of excellent Loran geometry and signal strength from the stations at Ejde, Vaerlandet and Anthorn.

Figure 4 shows a zoomed-in view of the islands, showing their size and detail. And the Orkney terrain is very much like the low lying islands off the Finnish coast; mainly flat, with rolling hills, some cliffs, but nothing too mountainous.

Figure 4 – A close-up view of the Orkney Islands.

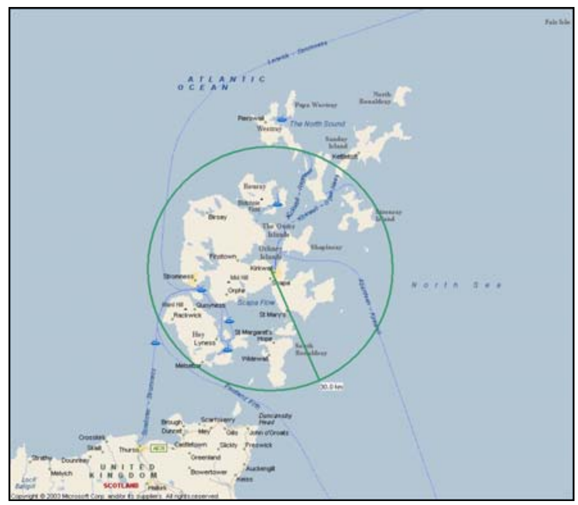

Figure 5 – Temporary dLoran Reference Station installed in Kirkwall.

3. TRIAL SET UP. The trials took place between the 27 June and 3 July 2009. The base of operations was the capital city of Kirkwall where the Northern Lighthouse Board have a depot. It was there that we installed a temporary differential-Loran Reference Station.

Figure 5 shows a circle with Kirkwall at the center. The radius of the circle is an assumed 30km estimated range of the Reference Station. This assumption was obtained from an analysis of the work done by the United States Coast Guard Academy (USCGA) [1]. So we have the potential of covering a large area of the islands with a single Reference Station.

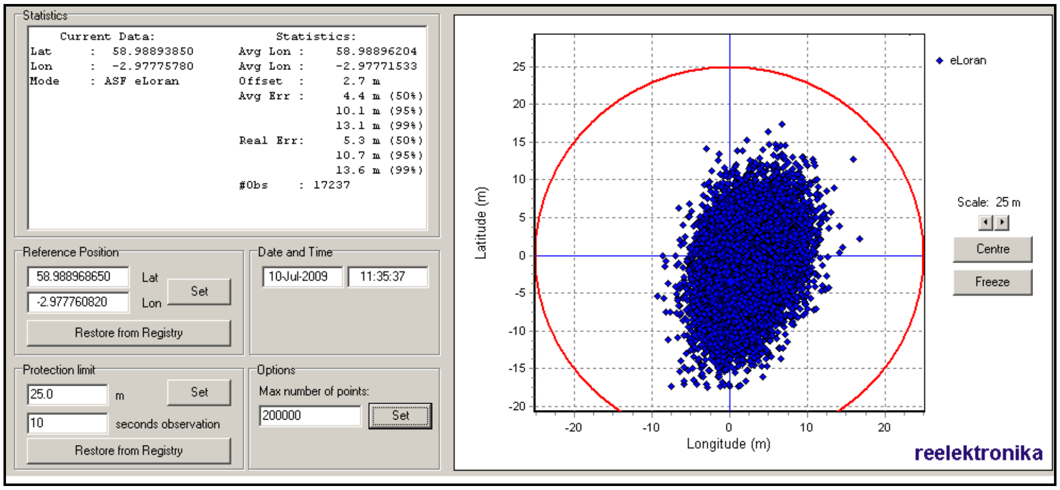

Figure 6 – Static data measured over the 27th June 2009, showing 10.7m(95%) accuracy performance. Note the information shown in the 'Date and Time' text-box of the left hand panel is the date and time that the data were post-processed, and is NOT the date and time of the original measurements.

The Reference Station was set up onboard the GLA's Mobile Measurement Unit (MMU). The equipment employed included:

- A Fleet Broadband Sailor 250 satellite Internet modem and antenna – this would allow us to transmit differential corrections in real-time, and control the reference station from the bridge of the survey vessel.
- The Reelektronika dLoran Reference Station hardware – for monitoring the Loran signals and computing differential corrections.
- A differential-GPS receiver for surveying the position of the reference station.

The Loran antenna was mounted on an extendable pole to raise it away from any local interference caused by computer equipment in the MMU.

The Reference Station hardware contains a Novatel timing grade GPS receiver, used for providing GPS time for measuring the nominal ASF at the station, a Loran receiver, some digital time-tagging hardware and a PC.

4. SOME STATIC RESULTS. Figure 6 shows 24 hours of static data measured at the Reference Station. The data was post-processed by re-running the logged data back through the monitoring software, provided by Reelektronika, installed on the PC within the measurement unit.

There are three error measures that are of interest:

- The "Average Error" is the degree of scatter from the centre of the cluster of points – the average Loran position – this is affected by short-term transmitter variations, interference, noise, and any rapidly changing propagation conditions.
- The "Offset" is the difference between the centre of that cluster and the actual surveyed position – this is affected by longer term temporal decorrelation effects, for example diurnal and seasonal effects affecting the nominal ASF measured at the Reference Station installation. The aim of differential-Loran is to minimize this offset as much as possible.
- The "Real Error" is the error, which includes the "Average Error" and the "Offset".

So we see a Real Error of 10.7m (95%) with an offset of 2.7m.

Of course, it is possible to send differential corrections down to Anthorn via the Internet. And if we were then to receive them back over Eurofix we would see the system gather these scattered points in slightly towards the reference location, and the Offset would be closer to zero. However, this data was measured with differential mode off, hence the build up of the offset over time.

Figure 7 shows static results measured aboard the survey vessel over the 28th June 2009, computed using the GLAs' proprietary software. The positioning accuracy in this case was found to be

6.1m (95%). The improvement over the Reference Station case is most likely to be due to the vessel installation having a quieter radio noise environment than that at the Reference Station.

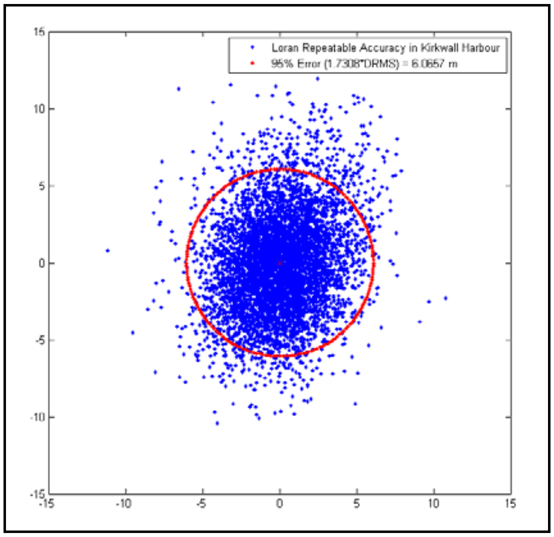

Figure 7 – Static data measured on the bridge of the survey vessel while docked in Kirkwall overnight on 28th June 2009.

5. DYNAMIC TRIALS. Figure 8 shows the three routes of the dynamic trials, sailed over each of three separate days.

In what follows, we refer to these routes as Red, Blue and Green, and they were performed in that order. The total distance covered was some 230M. It was the longest Loran trial that the GLAs have performed to date.

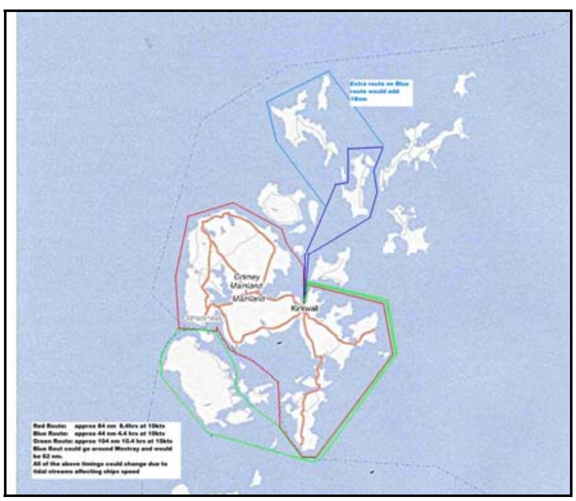

Figure 8 – The three routes of the dynamic trials.

The vessel employed for the survey was a buoy tender belonging to the Northern Lighthouse Board, the NLV "Pole Star" (see Figure 9).

For the purposes of the trials, the equipment used was a Reelektronika eLoran Monitor System (LMS). The unit is much simpler than the Reference Station unit. It still contains a Loran receiver, a GPS receiver and a PC, but it is not designed to make true TOA ASF measurements since it does not contain any time tagging hardware. The aim of the Orkney trial was to assess Loran performance and this equipment was designed for that purpose. An aim of the GLAs is to have one of these units permanently installed on each of our six vessels.

Figure 9 – The NLV Pole Star.

Using the supplied software it is possible to make precise measurements of the positioning error between Loran positions and Eurofix corrected Differential-GPS positions. The software installed on the unit allows the production of scatter plots and summary statistics as though the unit was static, using the DGPS position as the ground-truth. That process will be the basis of the results discussed in this paper.

It was found that Eurofix corrected GPS provided 4m (95%) accuracy performance during the Orkney trial. While not optimal, this ground-truth accuracy level allows a first look at the Loran accuracy performance. It is important to note, however, that the Loran results shown in what follows are somewhat diluted by the accuracy of the ground-truth, and actual performance is expected to be better than those shown in general. In future trials, a more precise ground-truth will be employed. It is probably sufficient to use radiobeacon DGPS for this purpose, with it's accuracy of 1 to 2m.

6. A NOTE ON POSITIONING MODES. The Loran Monitor can operate in various positioning modes. It can produce positions based on autonomous

Loran – with no ASFs and no differential corrections. It is also possible to upload ASFs to the receiver and so operate in ASF corrected Loran mode.

The unit can also calibrate Loran against GPS, and that is almost like having Loran ASFs everywhere without having to go out and make measurements. But there are some caveats to that statement, which will become obvious in the results discussed later.

Finally, the unit can perform differential-Loran – thus correcting for temporal changes in the ASF data. This latter mode is eLoran for Harbour Entrance and Approach.

It is important to make the distinction between what is eLoran, and what is not.

The main aim of the trial was to assess Loran performance around as much of the Orkney Islands as possible over the three days. For the most part, we monitored GPS **calibrated Loran** during the trial, to give us an indication of the performance of Loran in the region – but this mode of operation certainly is not eLoran. With calibrated Loran the receiver continuously compares DGPS and Loran, and adjusts the Loran pseudoranges accordingly. It can be used as a quick check and a sanity check but, for reasons shown later, it should not be relied upon wholly to demonstrate eLoran's performance.

7. POST-PROCESSING VS. REAL-TIME. In the main, post-processing is used demonstrate the results of the trial. For the early results the logged data was run back through Reelektronika's logging software to produce the scatter plots and statistics. But during the data analysis phase we rapidly switched over to using our own proprietary software. Software was written to form our own positioning solutions, produce error plots and ASF grids, and to apply differential-corrections in post-processing.

A live real-time dLoran harbour entrance and approach was attempted, but unfortunately technical difficulties resulted in our inability to accomplish satisfactory results during our time in the islands. A new trial, held at a later date, will rectify this.

8. RESULTS. As mentioned earlier the trial was split into three different routes. Figure 10 shows the Red Route, sailed on the first full day of the trial. The vessel started off in Kirkwall in the morning and headed round the coast of the mainland, through the Hoy Sound, Scapa Flow and back through the Shapinsay Sound to Kirkwall.

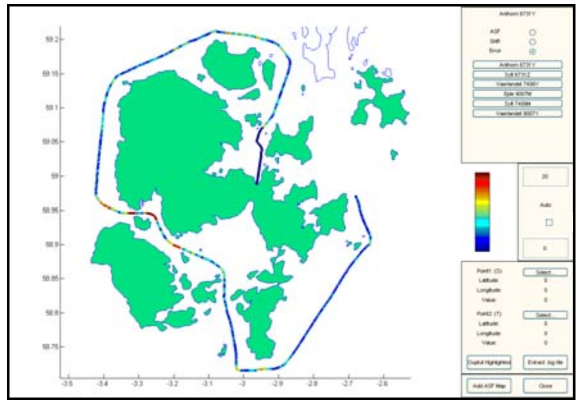

Figure 10 – The Red Route – Instantaneous error plot.

The colour coded plot shows the instantaneous position error between the calibrated Loran result and Eurofix derived DGPS. The key shows lower and upper limits of 0 and 20m. There are various points along the route where there are "hotspots" of relatively high positioning error, up to 20m and beyond.

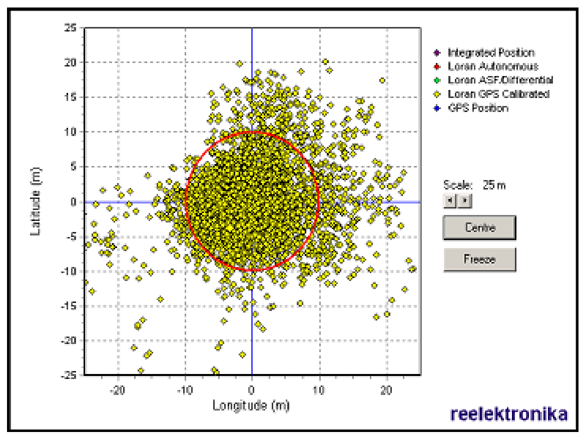

Figure 11 – Scatter plot of Red Route.

Unfortunately, we have some missing data as we head back towards Kirkwall, so this area is not included in the analysis.

The scatter plot of Figure 11 gives 15.7m (95%) over the entire route.

Figure 12 illustrates the blue route showing one or two error hotspots. The scatter plot is shown in Figure 13. There is again some missing data at the start, this time caused by a loose antenna connector. Positioning error was found to be 11.3m (95%) along the entire route.

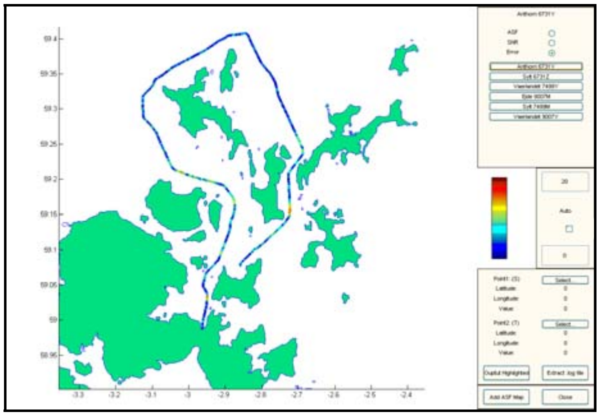

Figure 12 – The Blue Route.

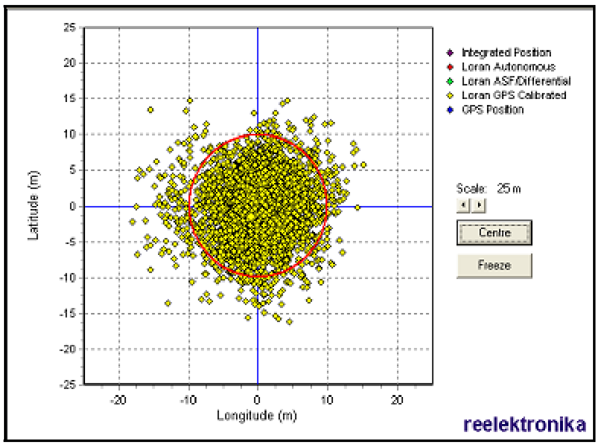

Figure 13 – Scatter plot of Blue Route.

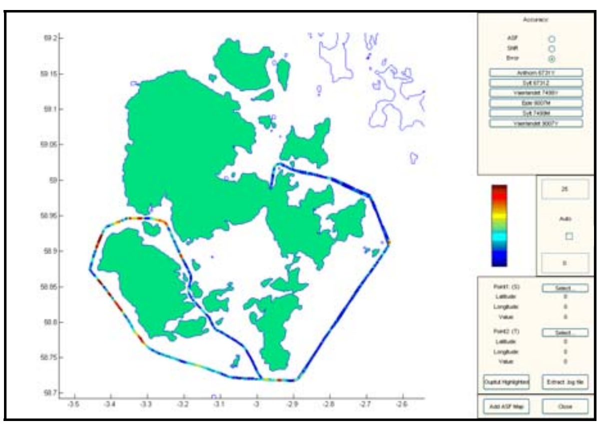

Figure 14 – The Green Route.

Finally, the Green Route and its associated scatter plot are shown in Figure 14 and Figure 15. The position error along this route was found to be 21m (95%). And again there were some large instantaneous position errors.

Looking at the individual routes each as a whole then gives us a general feeling of Loran performance over the entire area, but we really would also like to talk about Loran performance in specific areas of the Orkneys.

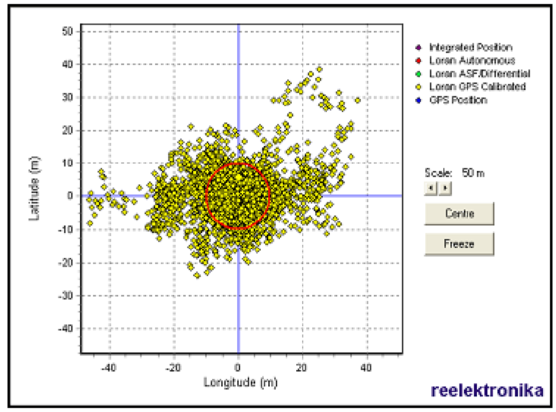

Figure 15 – Scatter for the Green Route.

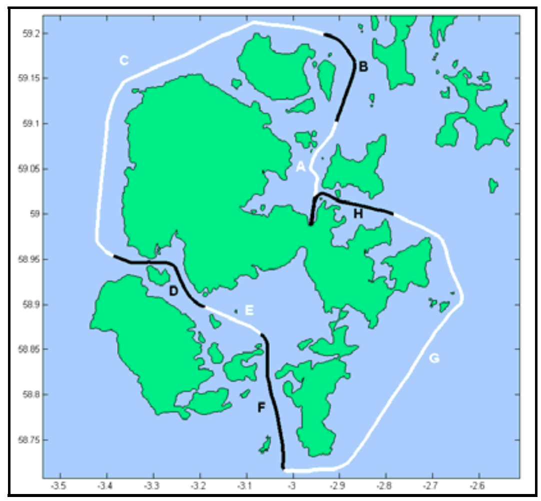

Figure 16 – Segmentation of the Red Route.

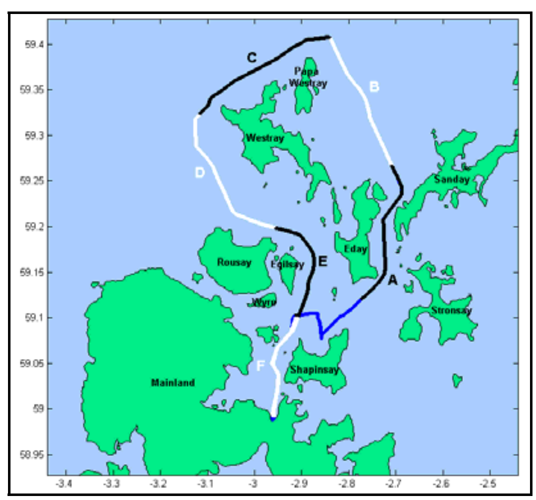

Figure 17 – Segmentation of the Blue Route.

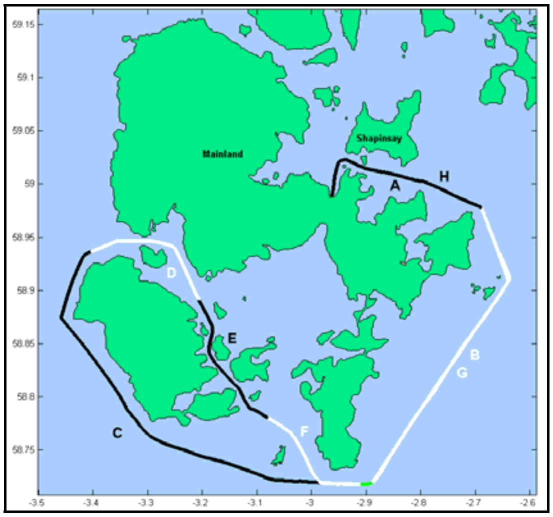

Figure 18 – Segmentation of the Green Route.

We can do this by dividing the data into segments along the individual routes. Figure 16, Figure 17 and Figure 18 show each of the routes separated quite arbitrarily into various segments, each segment assigned a letter of the alphabet. Now we can run the data for each of these segments through the Monitor's processing software and generate the same statistics as for the whole routes.

Segment ID	Overlaps with …	Calibrated (Real Error) m (95%)
Red A	Blue F	13.1
Red B	Blue E	11.2
Red C		12.6
Red D	Green D	29.7
Red E		20.8
Red F		12.0
Red G	Green B, G	11.8
Blue A		13.1
Blue B		7.4
Blue C		8.1
Blue D		11.9
Blue E	Red B	11.7
Blue F	Red A	12.1
Green A	Green H	10.5
Green B	Red G, Green G	10.3
Green C		27.3
Green D	Red D	35.9
Green E		16.3
Green F		14.5
Green G (Extrapolated)	Red G, Green B	13.3
Green H	Green A	10.8

Table 1 – Results of analysis of all segments from all three routes.

Table 1 shows the results for calibrated Loran. The table entries are colour coded to easily identify segments showing larger errors. So green is less than 20m, amber between 20 and 25 and red greater than 25. And we can see for the most part that we get greens.

So looking at Red A (Figure 16) for example, the area leaving Kirkwall we get 13.1m (95%) from the table. We now of course highlight problem areas. According to the table Red D, the passage through the Hoy Sound, shows a position accuracy of 29.7m, well outside our 20m requirement. We can also see that Green D, which overlaps with Red D, shows a similarly high position error of 35.9m (95%). So there is something happening in the Hoy Sound, which results in these large position errors, and this warrants further investigation.

9. FURTHER ANALYSIS: THE HOY SOUND.

Figure 19 shows a snapshot of the instantaneous error in the Hoy Sound.

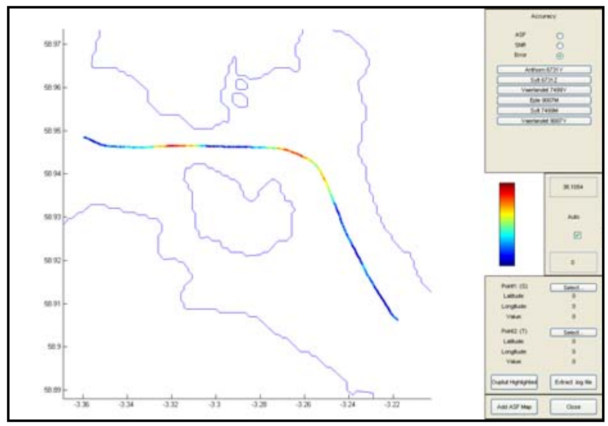

Figure 19 – Instantaneous position error through the Hoy Sound.

In this zoomed in view we can see something peculiar. We enter the Sound on the left and as we travel along our error starts low and slowly builds up. Then it drops, then it builds up again, until it finally falls away once more as we head out of the Sound.

Perhaps this is the result of propagation effects? However, we are operating in calibrated Loran mode, and we would expect to be compensating for propagation effects. We are supposedly continuously measuring ASFs. Of course the calibration is not happening every Loran measurement epoch-by-epoch (every 10 seconds), because if it were we would get zero position error in our comparison with DGPS.

So calibration is occurring regularly but with a longer period, or time-constant, than the Loran measurement epoch. In fact Reelektronika use the average of the last 300 seconds worth of GPS and Loran measurements to calibrate Loran [2]. This means that a receiver on a vessel travelling at 10kts would therefore be using the last 1.5km worth of GPS vs. Loran data to calibrate the Loran pseudoranges. So there is a large amount of smoothing going on.

This can be seen in the measured data and is discussed next. To do this we need to talk a little about ASFs.

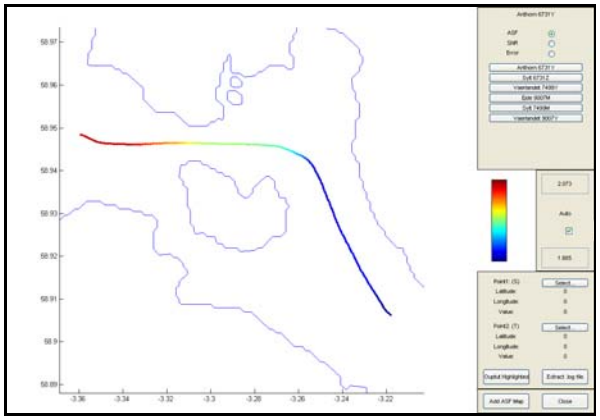

Figure 20 – Anthorn-Ejde Differential-ASFs measured along the Hoy Sound – as output directly by the receiver in the LMS.

Now we did not have an opportunity to measure true TOA ASF data along any of our routes – the trials were not designed with that in mind.

But Figure 20 is a plot of Differential ASFs as output directly by the LMS measured during the Hoy Sound run. Differential ASFs are calculated in transmitter pairs, assuming one of the station's has a true TOA ASF of zero. They are calculated a bit like the old Time Difference-ASFs, and as such they do not need a sophisticated time tagging system to produce. They can even be calculated cross-chain. In a positioning solution DASFs behave exactly like true TOA ASFs. And interestingly, these DASFs output directly by the receiver are in fact the products of the GPS calibration process.

So Figure 20 shows Anthorn-Ejde Differential ASF, with Ejde assumed to have a zero TOA ASF. The values fall from over 2 microseconds as we enter the Sound down to 1.7 microseconds as we leave.

The main thing to note about the plot is that the data are very smooth.

Figure 21 shows a plot of these DASFs along with the instantaneous positioning error along the Hoy Sound. Anthorn-Ejde and Vaerlandet-Ejde DASFs are shown in two shades of blue. The positioning error here is in green. As we travel through the sound, so we move along the graph from left to right. The DASFs are fairly flat at the start in Section A of the graph, changing only very slightly as we move along. But the positioning error increases from zero at the start, to over 30m. Then it suddenly drops in section B, again rising through Section C, and falling again. It is as though there is a lag between the positioning error and the DASFs, which are designed to correct for that error. There's too much smoothing going on.

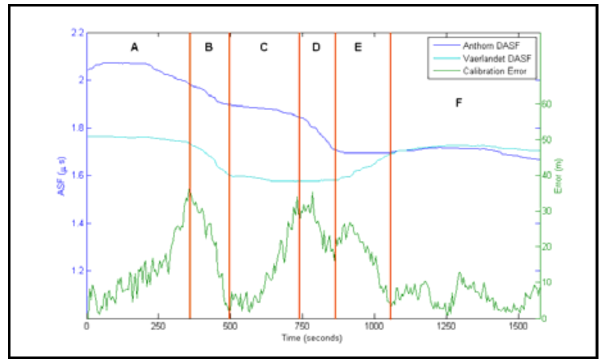

Figure 21 – Plot comparing instantaneous positioning error against DASF in the Hoy Sound.

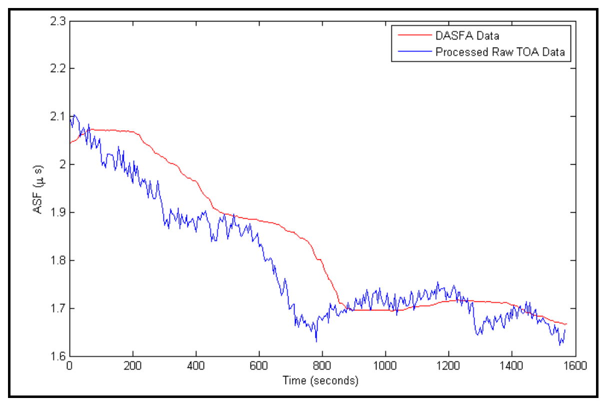

Figure 22 – Comparison of DASF data as directly output by the receiver, and GLA proprietary DASF calculations.

The blue plot, shown in Figure 22, is based on processing the raw Loran Time Of Arrival measurements and computing our own DASFs epoch-by-epoch using GLA proprietary software. The red plot shows the DASFs coming out of the receiver directly (the products of the calibration) and we can see there is a lag of some 200 seconds or so – about the same order of magnitude as the degree of smoothing used for calibrating Loran. The very act of using calibrated Loran is causing our positioning error to inflate.

Now we are not proposing that GPS calibration of Loran is a bad thing, far from it. It is useful to demonstrate the potential performance of Loran in the absence of ASF data, and no doubt it will be used in the future for navigation. The act of smoothing reduces noise and ensures that should

GPS drop out, you still have a calibrated Loran solution to navigate with for a short time.

But it cannot fully replace ASF corrected Loran in regions of rapidly changing coastline and terrain. Calibrated Loran needs to be used carefully and is not particularly appropriate used alone for assessing eLoran performance. Once again, GPS calibrated Loran is NOT eLoran.

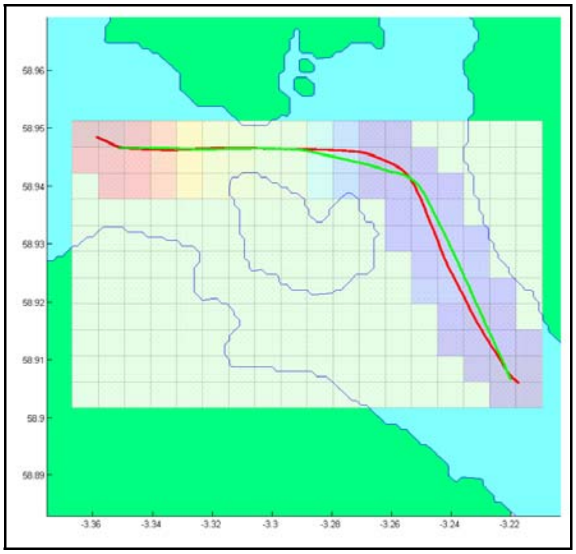

Figure 23 – DASF grid formed from GLA measured DASFs.

Now that we can measure our own DASF data we can process it into grids, as would happen if we were to publish the data and store it within a receiver. Figure 23 shows a grid consisting of 500m by 500m DASF elements or cells.

Each of these cells was assigned the average value of the DASF data found within it from the raw measurements made during the Red Route. We used extrapolation to extend the size of the grid by one cell either side of the vessel's track. This DASF data was stored within Matlab and, using the TOA data from the Green Route, which we sailed a few days later, we computed our own position solutions having applied the DASF data grid to the Loran TOAs. The accuracy performance was then analysed. The software we have developed allows us to create ASFs grids of any desired resolution.

Table 2 shows a comparison between the calibrated Loran result, which is slightly different than our original calibrated result because the amount of data has been trimmed down to fit the grid.

Looking at the Real Error column we can see that the positioning error varying against grid cell size. For our original 500m grid we now see 11.9m (95%) positioning error. This is a considerable improvement over the 24.5m (95%) calibrated Loran result.

From the table we can also see that this is actually the minimum positioning error across these various grid sizes. Interestingly, 500m agrees with the figure found to be optimal by Greg Johnson and his team during their own trials [3] [4] [5]. The error increases again at 100m cell size because the cells are so small that some of the green segment points lie outside the DASF database, where that DASF data is assigned to be zero.

So using an ASF grid has now better represented the coastline variation along this passage.

Grid Element Size (m)	Position Error		
	Average m (95%)	Real m (95%)	Offset (m)
Calibrated	24.1	24.5	5.8
1000	12.5	14.3	3.2
750	11.9	12.7	3.0
500	10.3	11.9	2.9
400	11.6	12.0	2.1
300	11.2	12.4	3.1
250	10.0	12.0	2.9
200	11.2	12.3	2.8
150	13.0	15.6	4.1
100	38.2	47.6	9.6

Table 2 – Positioning error vs. DASF cell size for Hoy Sound.

10 APPLYING DIFFERENTIAL CORRECTIONS.

Now, the DASFs that we used were measured three days previously. We can therefore expect there to be some temporal variation in the actual values over that period, and the effect of this can be seen in the size of the offset, which is quite large.

But we should be able to compensate for these temporal variations because we have a reference station 20km away in Kirkwall, which although not transmitting differential corrections was certainly logging them.

As mentioned earlier we did not have the opportunity to do real-time dLoran during the trials, but we can apply corrections in post-processing.

For this purpose we used the same 500m grid of DASFs from the Red Route and processed them using differential-Loran Reference Station data. We simulated exactly what a Reference Station does when actually transmitting the corrections by applying corrections in transmitter pairs every 30 seconds throughout the data. We also applied a 10-minute moving median filter exactly as done by the Reference Station before broadcasting the corrections. The results are shown Table 3.

Filtering Type	Filtering Amount	Update Interval (Seconds)	Real Error (95%) (m)	Offset (m)
Calibrated	N/A	N/A	24.5	5.8
Non-differential (ASF Only)	N/A	N/A	11.9	2.9
None	N/A	10 (epoch-by-epoch)	16.2	1.4
Median Filter	10 Minute Window	30 per pair	10.9	0.6
Exponential 3 Mins	$\alpha = 0.05$	30 per pair	11.6	0.9
Exponential 8 Mins	$\alpha = 0.02$	30 per pair	11.0	1.2
Exponential 16.5 Mins	$\alpha = 0.01$	30 per pair	10.7	1.3

Table 3 – Comparision between calibrated result and differential correction results using various filtering methods.

Highlighted in red is our calibrated result. The previous non-differential result using our own measured 500m DASF grid is also shown for comparison. When we apply differential corrections using the "transmission" scheme mentioned above we get the result highlighted in green. We have improved the scatter and reduced the offset, and we now see 10.9m (95%).

We also experimented with other filtering methods, and with no filtering and epoch-by-epoch application to see what would happen, but it seems that the way the Reference Station currently does it is the best all-round.

So our final eLoran result for the Hoy Sound is then 10.9m (95%) positioning error, remarkably using a Reference Station 20km away on the other side of the mainland!

11. SOME OTHER SEGMENTS. We then went on to identify other segments where we had repeated runs, measuring DASF along one route and applying them during a second route run later in the trials. Three examples of these are shown in Figure 24, Figure 25 and Figure 26.
In the set of runs shown in Figure 24, for example, we left Kirkwall in the morning and returned in the evening. So we use the DASFs we as we left for the day and applied them at the end of the day as we returned, all in post-mission processing, simulating a harbour entrance and approach with eLoran.

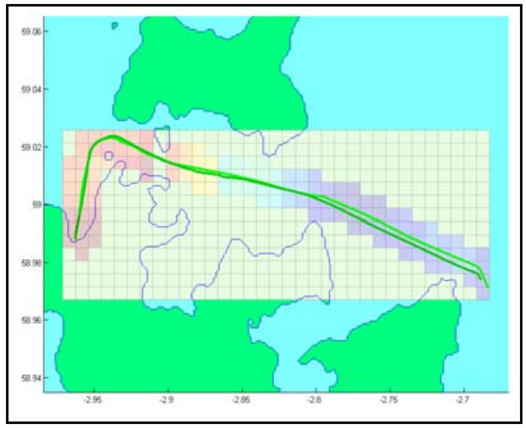

Figure 24 – Kirkwall Approach via Shapinsay Sound.

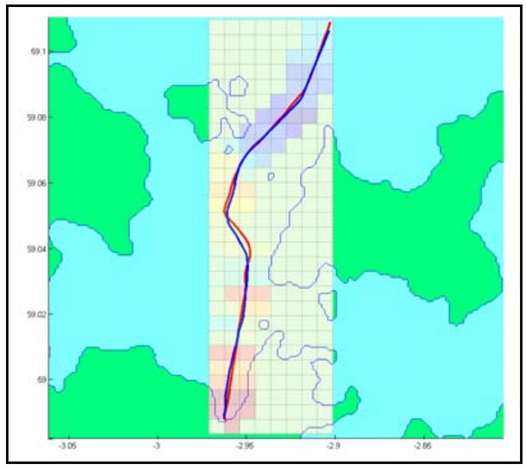

Figure 25 – Kirkwall Approach via Holm of Boray.

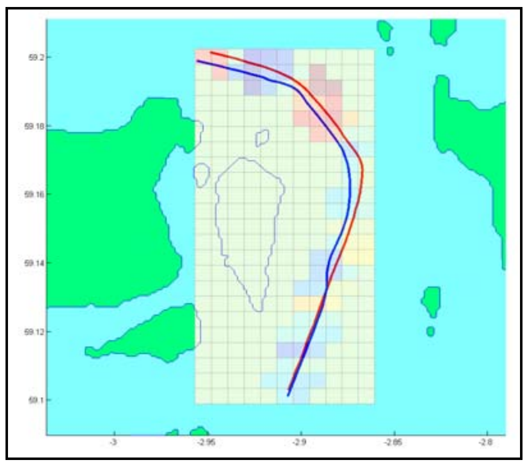

Figure 26 – Westray Firth.

Area Name	Positioning Type	Average m (95%)	Real m (95%)	Offset (m)
Shapinsay Sound	Calibrated	10.8	10.8	1.2
	dLoran	13.5	15.0	3.2
Holm of Boray	Calibrated	12.0	12.1	1.0
	dLoran	12.7	12.9	2.5
Westray Firth	Calibrated	11.7	11.7	2.0
	dLoran	10.7	12.0	4.8

Table 4 – Calibrated vs. dLoran results for other example segments.

The results are shown in Table 4. Unfortunately, we see poorer performance from our dLoran results than calibrated Loran in these cases. And this is where calibrated Loran comes in very useful. It acts as a sanity check on our results. We should be doing better than calibrated Loran, or at least the same, because we have an ASF grid and dLoran. There is no long-term smoothing going on, the DASFs represent the coastline effects.

If the coastline effects vary slowly then, depending on the time-constant of calibration compared to an ASF grid resolution, the calibrated Loran will show performance comparable to dLoran.

The only conclusion then is that there is something wrong with the data coming out of the receiver, or with our processing methods! This obviously needs further investigation. At a first estimate though we can say the following.

The Hoy Sound data was produced by measuring the DASFs by traveling in a particular direction. We then went on to apply them in our positioning solutions while traveling in the **same** direction in which they were measured. With all the other three routes we measured DASFs by traveling in *one* direction, and then used them in positioning in the *opposite* direction. So we believe that there is a latency effect in the results related to a timing offset.

We do not see the effects in the Hoy Sound data because we were traveling in the same direction during measurement and application of the DASFs, and the effect is almost certainly cancelled out – or much reduced anyway. So we will need to look into this in further detail and consult with Reelektronika to establish the cause.

12. CONCLUSIONS. Our conclusions are split up into those related to the Orkney Islands, those related to Calibrated Loran and those related to Loran performance in Archipelagos.

Orkney Islands: Loran functions exceptionally well in the Orkney Islands, with no loss of signal, and with potentially sub 20m accuracy available in most places. We found position accuracy of 11m (95%) in the Hoy Sound using ASFs and differential-Loran (eLoran). We were successful in applying differential corrections from a Reference Station situated 20km away from the point of use of the differential correction data. The 500m ASF cell size agrees with US studies (Greg Johnson's team) and provides good results in the Hoy Sound.

Calibrated Loran: GPS Calibrated Loran is good for quick assessment of potential Loran performance. However, it is not optimal for demonstrating eLoran's maximum potential accuracy performance. If you represent a potential user community and are evaluating eLoran, be careful! Nothing can replace making ASF measurements and using the good quality TOAs coming out of modern receivers in your own position solutions. Calibrated Loran can, however, be used to identify regions of rapidly changing ASF, compared to the smoothing time-constant used for calibration, thus potentially identifying where ASFs should be measured. Calibrated Loran also serves as a very useful sanity check of eLoran results. Of course the degree of smoothing employed during GPS calibration can be made adaptable should receiver manufacturers allow this.

Archipelagos: There is no reason why eLoran should not work in archipelago areas assuming that there is good eLoran station geometry, good eLoran signal strength, and ASFs are mapped along important narrow channels to cater for rapidly changing coastline profiles. These ASF data would need to be augmented with dLoran to cater for temporal effects.

13. Further Work. The GLAs will further develop their proprietary software and enable it for use in live operation, in addition to furthering the post-processing capabilities.

The latency issue will need to be solved in consultation with Reelektronika. We will further post-process our data to fine tune our techniques and algorithms and investigate other areas where we have DASF data available and repeated runs.

Finally, we plan to revisit the Orkney Islands with more targeted tests in mind, including the measurement of absolute TOA ASF using our ASF Measurement Equipment, and perform a real-time live differential-Loran trial.

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